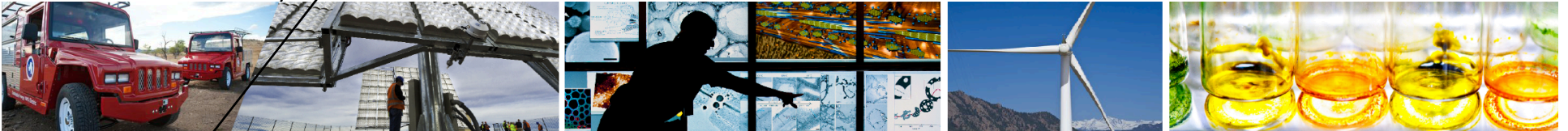


Frequency Response and Transient Stability in the Western Interconnection

WWSIS Phase 3 and Active Power Controls - Dynamics



Debbie Lew, Erik Ela, NREL
TRC Meeting, Dec 12, 2012

Western Wind and Solar Integration Study

Phase 1: Can you balance the system with high penetrations of wind and solar?

<http://www.nrel.gov/docs/fy10osti/47434.pdf>

Phase 2: How do high penetrations of wind and solar impact cycling costs and emissions? How do wind and solar impacts compare?

Phase 3: Can we maintain system reliability with high penetrations of wind and solar? What mitigation options can help? How do advanced features in those technologies impact reliability and stability?

Funded by DOE

Goal of WWSIS-3

Frequency response to large outages under a variety of system conditions

Large-scale transient stability, focusing on major WECC interties

Potential mitigation measures - how various active power controls can help

Note related effort by Sandia to examine small signal stability

Role of the Technical Review Committee

Meet every ~2 months

Oversee assumptions, methodologies, and inputs.

Ensure results are technically rigorous.

Provide linkages to related work/data as appropriate.

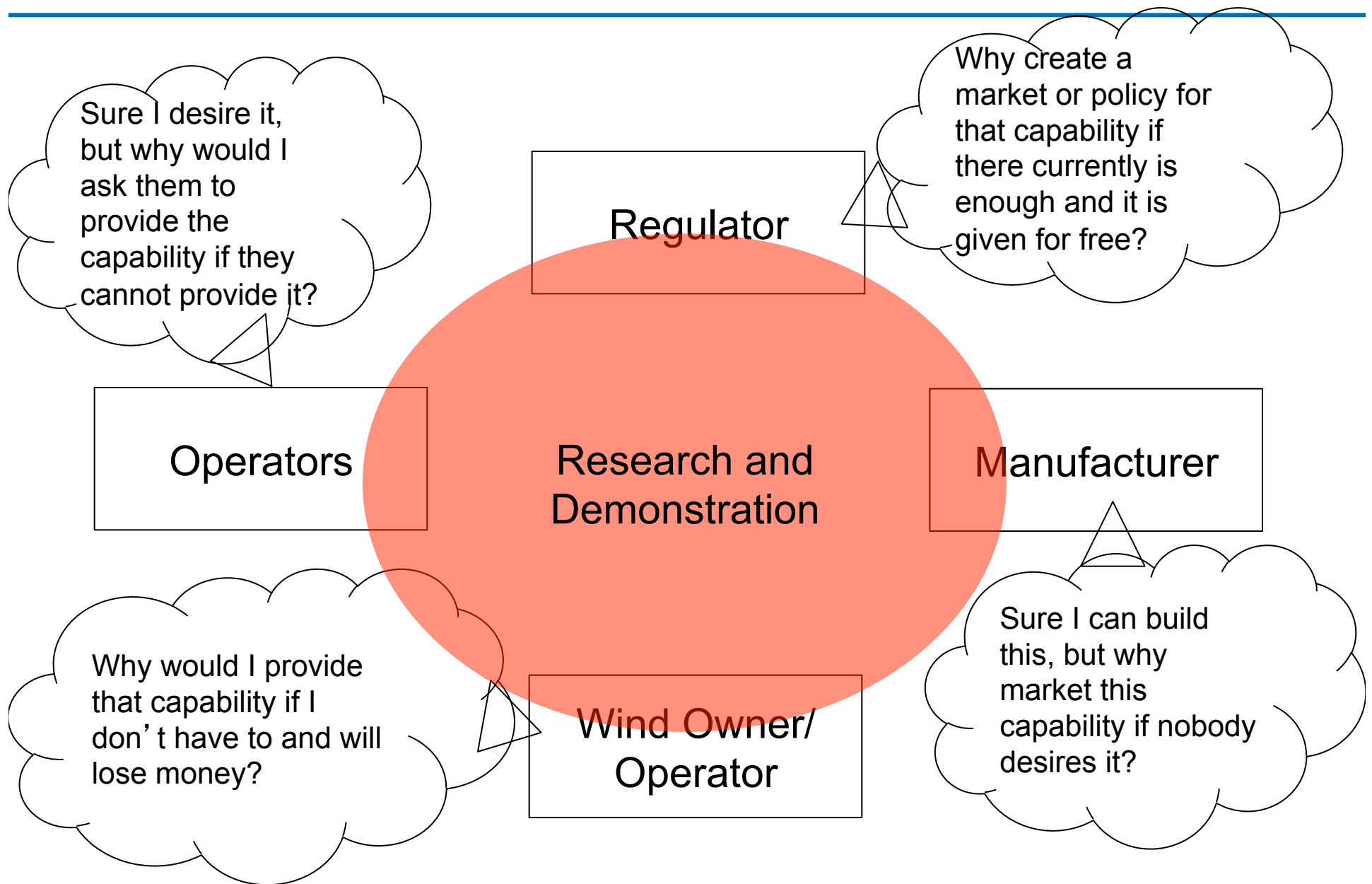
Goal of today's meeting

Overview, context and objectives

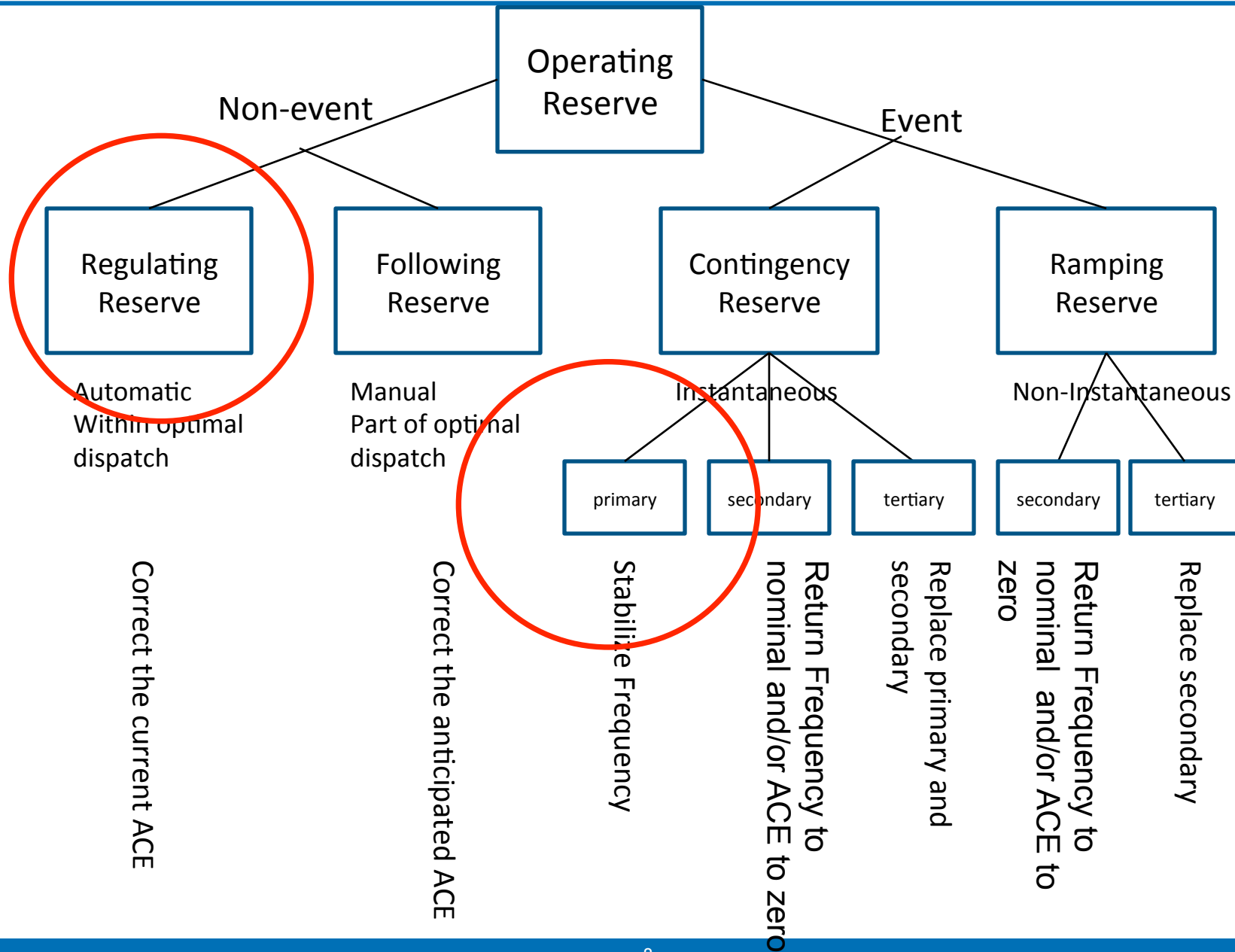
Discuss scope of work, focusing on GE tasks so that subcontract can be put into place

ACTIVE POWER CONTROL FROM WIND POWER NREL & EPRI JOINT PROJECT

Differences in Perspective



Operating Reserve Categorization

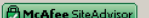



Objectives

- What is the technical feasibility of wind power plants providing APC?
- How does it affect the dynamic system response?
- How will its provision change the steady-state operations?
- Will its provision be economic for consumers? Will it be economic for wind plant providers?
- How will it impact the loading of the turbines and components? Will it affect the life of the turbine?
- How will policies and standards affect the designs?
- Are there advanced designs that can provide the tradeoff between structural loading and response performance?

Active Power Control from Wind Power Workshop 2011

http://www.nrel.gov/electricity/transmission/active_power_control_workshop.html




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Active Power Control from Wind Power Workshop

This workshop, held on January 27, 2011 in Boulder, Colorado, was convened to discuss the research needs and state of the art of providing active power control from wind turbines and wind plants. Here are the proceedings, [meeting notes](#), and [list of attendees](#).

The knowledge from the workshop will help guide research being conducted at NREL, the Electric Power Research Institute (EPRI), as well as at universities, utilities/independent system operators (ISOs), and manufacturers. The workshop included active power control in all forms, but in particular, it focused on the areas of inertial response, primary control (frequency response), and secondary control (automatic generation control regulation). Also, many utilities and ISOs are beginning to evaluate the potential for new standards and policies that relate to these types of control and therefore it is important that they have available the best information about these types of controls for making these decisions.

Introduction and Workshop Overview

[Erik Ela](#), NREL

R&D Objectives of NREL and EPRI

[Daniel Brooks](#), EPRI
[Vahan Gevorgian](#), NREL

ISOs/Utilities

Moderator, Daniel Brooks, EPRI

- [Sandip Sharma](#), ERCOT
- James Dominick, Xcel Energy (Please contact [James Dominick](#) for presentation)
- [Dale Osborn](#), MISO
- [Bob Cummings](#), NERC

Manufacturers

Moderator, Pouyan Pourbeik, EPRI

- [Nick Miller](#), GE
- [Bob Nelson](#), Siemens
- [Richard Springer](#), Vestas
- [Slavomir Seman](#), ABB

Universities

Moderator, Ed Muljadi, NREL

- [Vijay Vittal](#), Arizona State University
- [Mohammad Shahidehpour](#), IIT
- [Jim McCalley](#), Iowa State University
- [Mack Grady](#), University of Texas - Austin

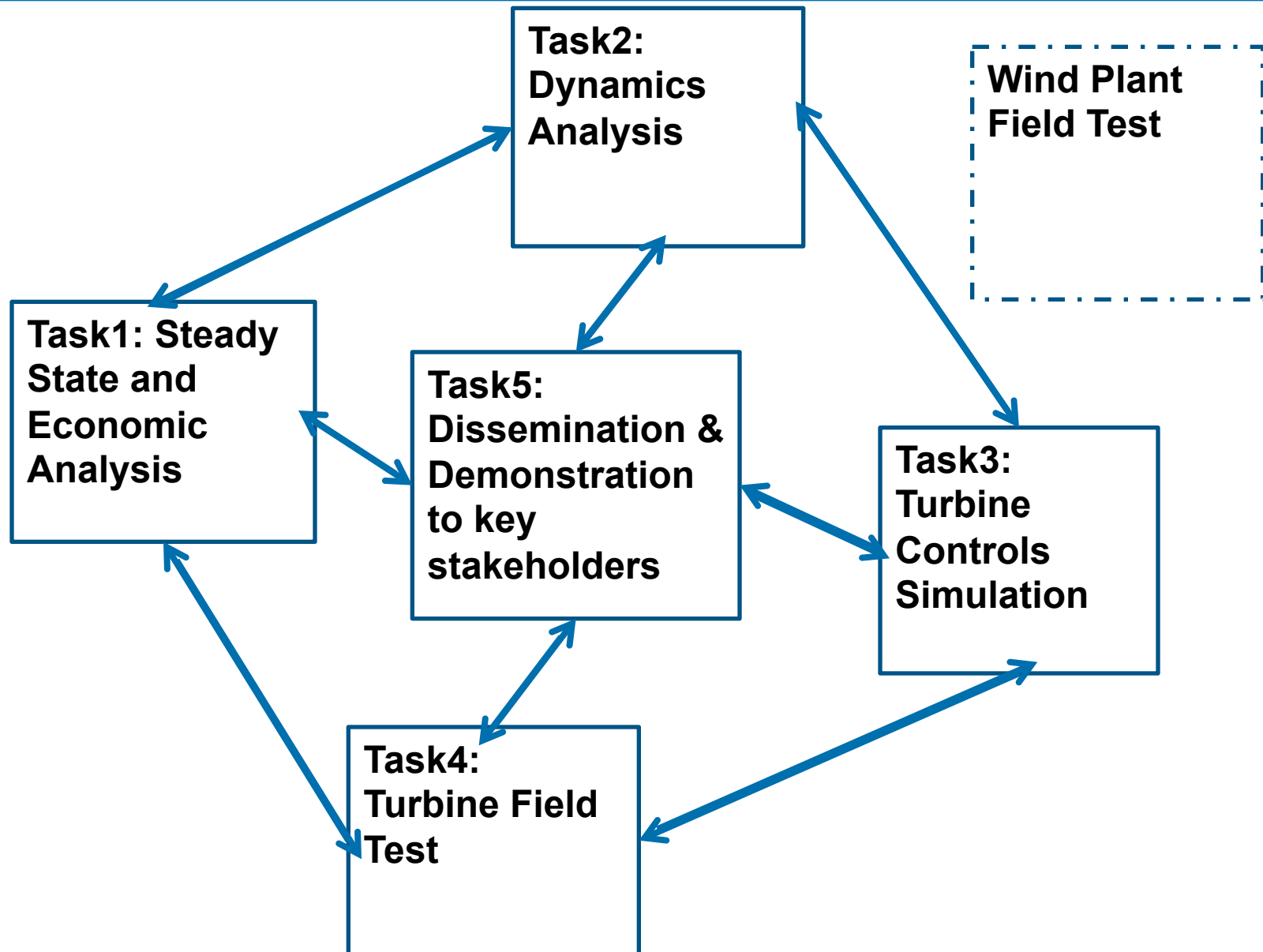
Group Discussion

Moderators: Erik Ela, NREL and Daniel Brooks, EPRI

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Project Tasks



Task 1: Economics Steady State

Issues with penalties in current market designs

Developed an SCUC model which incorporates primary frequency response scheduling and pricing

With market design found unit earned additional revenue when improving PFR capabilities.

Scheduling and pricing for inertia and PFR for isolated systems and systems part of large interconnections.

Link to the PFR reliability requirements

Market Designs for the Primary Frequency Response Ancillary Service—Part I: Motivation and Design

Erik Ela, Member, IEEE, Vahan Gevorgian, Member, IEEE, Aidan Tuohy, Member, IEEE, Brendan Kirby, Senior Member, IEEE, Michael Milligan, Senior Member, IEEE, Mark O'Malley, Fellow, IEEE

Abstract—The first part of this two-paper series discusses the motivation of implementing a primary frequency response (PFR) market in restructured power systems, as well as the market design that would create the right incentives to provide the response reliably. PFR is the immediate, autonomous response of generation and demand to system frequency deviations. It is the critical response required to avoid triggering of under- and over-frequency relays or instability that could lead to machine damage, load-shedding, and in the extreme case, blackouts. Currently, in many restructured power systems throughout the world, ancillary services markets have been developed to incentivize technologies to provide the services ancillary to energy provision in order to support power system reliability. However, few ancillary services markets include a market explicitly incentivizing the provision of PFR. Historically, PFR was an inherent feature available in conventional generating technologies, and in most systems, more was available than needed. However, recent trends in declining frequency response, the introduction of emerging technologies, and market behavior may soon require innovative market designs to incentivize resources to provide this valuable service.

Index Terms—ancillary services, energy markets, frequency response, power system economics, power system operations, power system reliability, unit commitment, variable generation.

NOMENCLATURE

f_{ss} : Time associated with steady-state frequency (s)
 f_{rec} : time required to recover to nominal frequency (min)
 $P1^{Req}$: PFR capacity requirement (MW)
 $P1^{ssReq}$: PFR requirement at t_{ss} (MW)
 $P1^{NadirReq}$: PFR requirement at t_{Nadir} (MW)
 $P2^{Req}$: Secondary/contingency reserve requirement (MW)
 Δf_{max} : maximum frequency deviation (Hz)
 Δf_{band} : maximum dead band allowed (Hz)
 P : Energy schedule (MW)
 $P1^0$: Full PFR availability (MW)
 $P1^{Nadir}$: PFR availability at nadir time (MW)
 $P1^{ss}$: PFR availability at steady-state time (MW)
 $P2^{spin}$: spin secondary reserve available (MW)
 $P2^{nonspin}$: nonspin secondary reserve available (MW)
 u : integer variable of unit being online [0,1]
 γ : integer variable of whether governor is enabled [0,1]
 χ : integer variable of having headroom for PFR [0,1]
 α : sensitivity factor of PFR capacity with time (unitless)

i, NG : generator index, set of generators
 $t, \Delta T$: time interval index, time interval set
 b, NB : bus index, set of buses
 G_{noGov} : set of generators with no governors enabled
 A : area or market region

Erik Ela is an Engineer with the National Renewable Energy Laboratory specializing in power system operations, market design, and the integration of renewable and emerging technologies into power systems. He previously worked with the New York ISO developing and improving products for operations and market design.

Aidan Tuohy is Senior Project Engineer with the Electric Power Research Institute specializing in research on planning and operations with large amounts of variable generation connected to the bulk electricity system. He has a Ph.D. in the area of operational and policy issues for systems with significant wind penetration from University College Dublin.

Michael Milligan is a Principal Researcher with the National Renewable Energy Laboratory. He is co-lead for the North American Electricity Reliability Corporation Integrating Variable Generation Task Force on probabilistic methods. He has published more than 140 papers, reports, and book chapters.

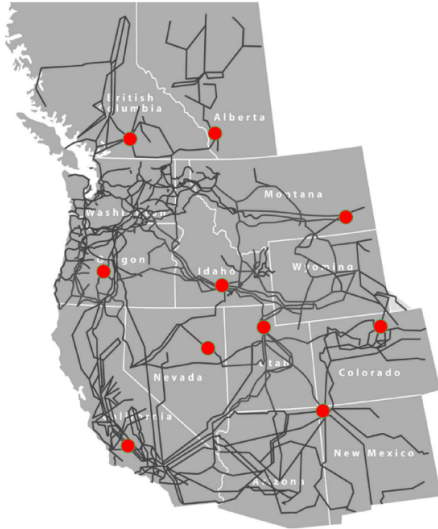
Brendan Kirby is a private consultant to the National Renewable Energy Laboratory and other clients. He has 36 years of electric utility experience and has published over 150 papers, articles, and reports on ancillary services, wind integration, restructuring, the use of responsive load as a bulk system reliability resource, and power system reliability.

Alternative Approaches for Incentivizing the Frequency Responsive Reserve Ancillary Service

Frequency responsive reserve is the autonomous response of generators and demand response to deviations of system frequency, usually as a result of the instantaneous outage of a large supplier. This article discusses the issues that can occur without proper incentives and even disincentives, and proposes alternatives to introduce incentives for resources to provide frequency responsive reserve to ensure an efficient and reliable power system.

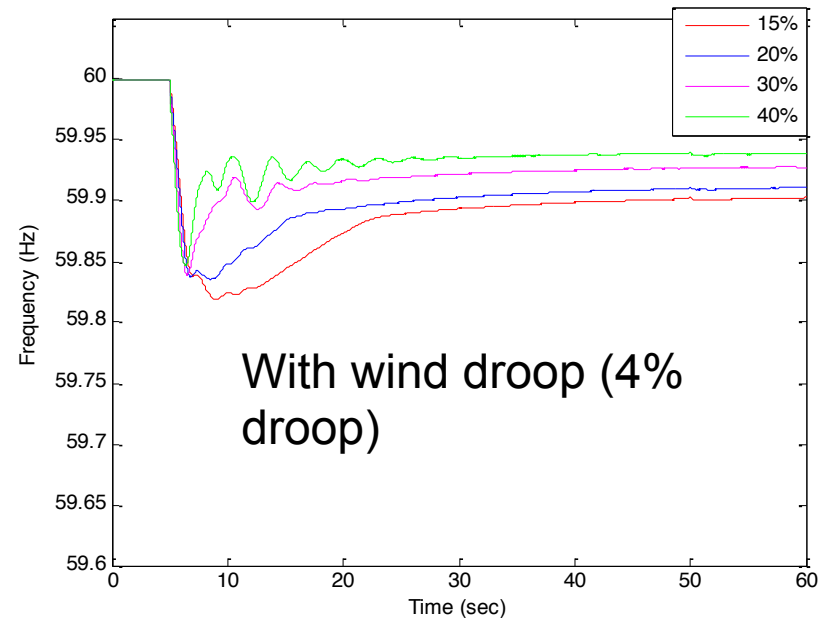
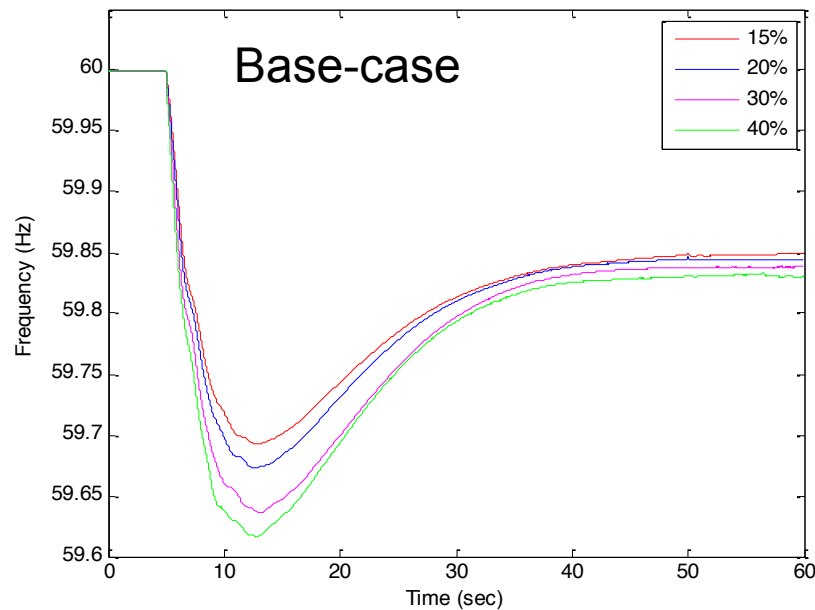
Erik Ela, Aidan Tuohy, Michael Milligan, Brendan Kirby and Daniel Brooks

Task 2: Dynamics Analysis

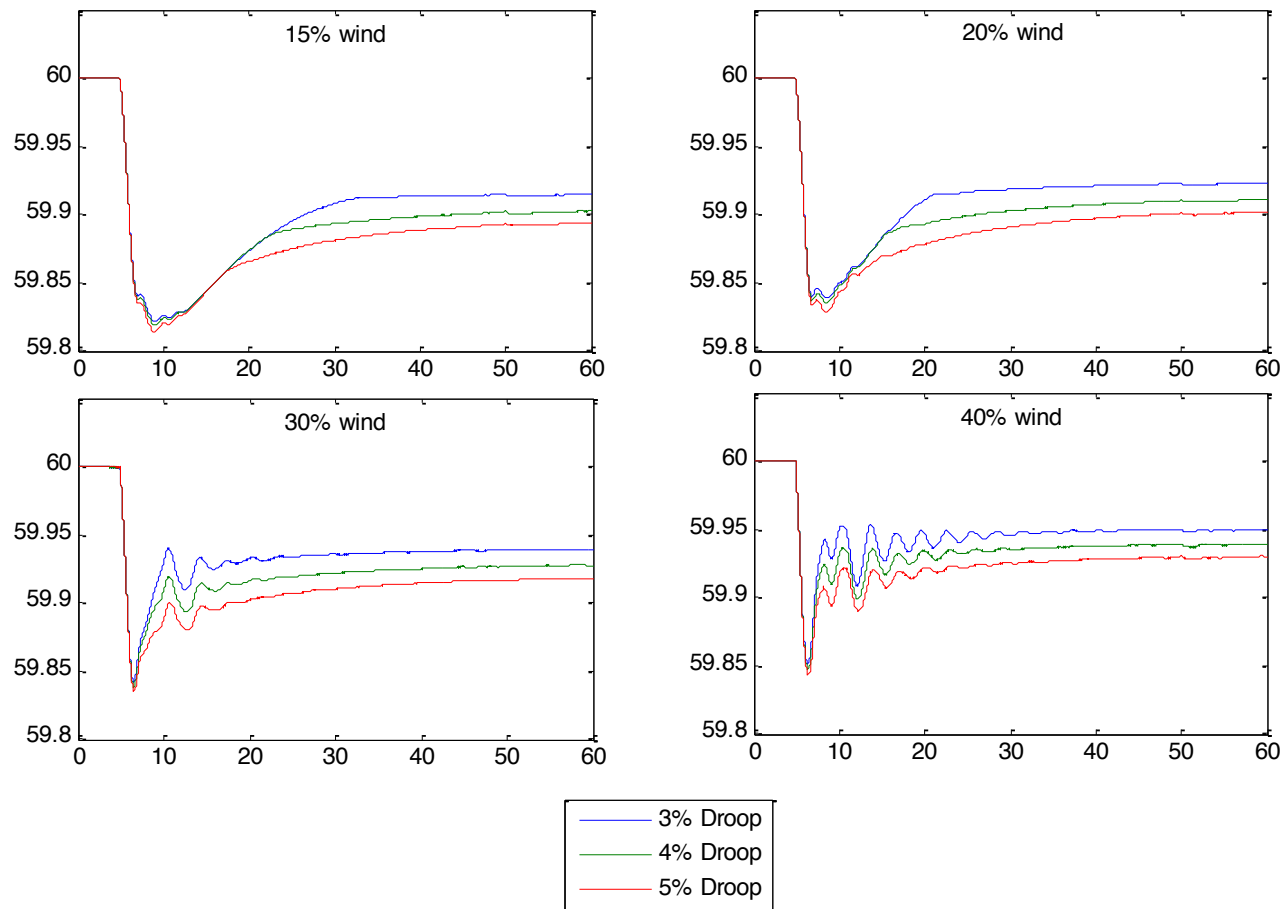


For each penetration level, the wind generation was added throughout the WECC region with 30% in California, 40% in South/South Central and 30% in North West

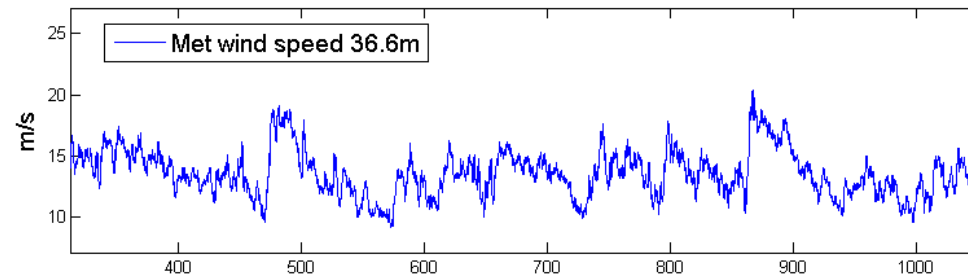
Frequency response from WECC is calculated by averaging frequency measurements at 10 buses across the interconnection



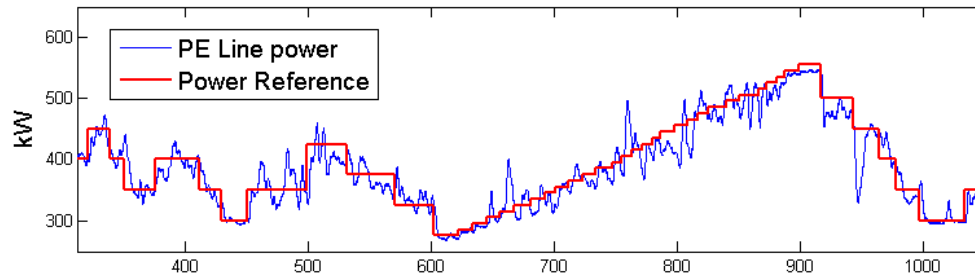
Varying wind droop



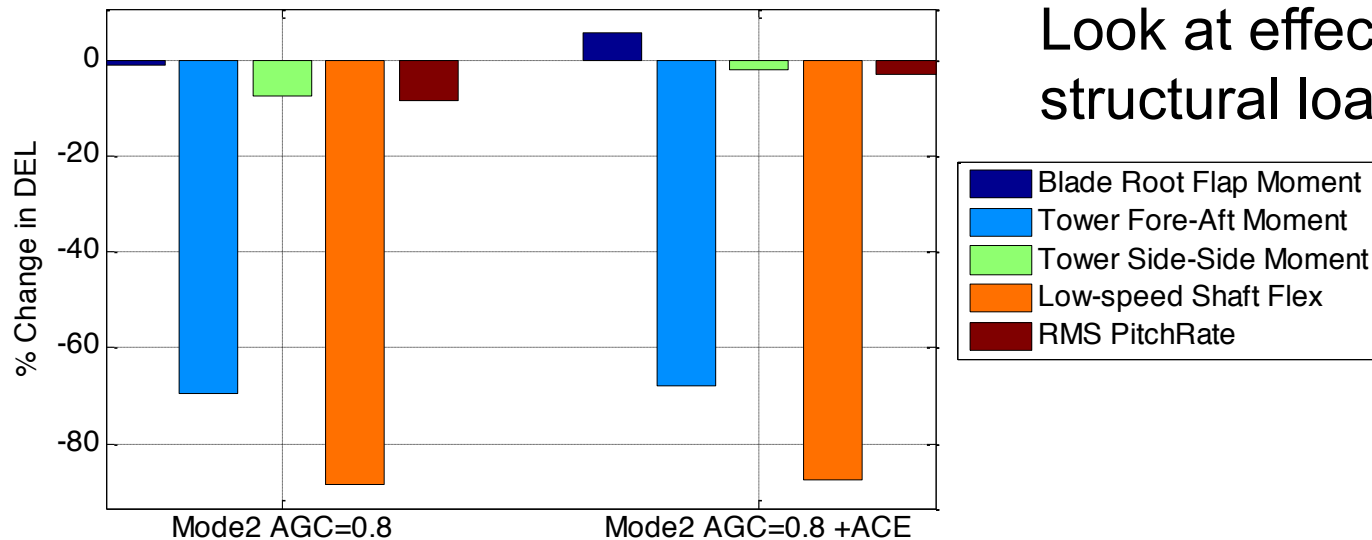
Task 3-4: Controls Design and Testing



Evaluate captured power against theoretically available



DELs Normalized to Baseline Controller (100% Power Capture)



Look at effects of APC on structural loads

Upcoming Activities

- Active Power Control from Wind Power Workshop: Follow up workshop from January 2011 workshop in Boulder, CO
 - Spring 2012, TBD
 - APCWP 1 stakeholder group, WWSIS3 stakeholders invited
- Project report: Draft complete, final anticipated prior to workshop
- Numerous papers on each task completed and further planned
- Following on industry activities, BAL-003, PFR market designs, etc.
- Field test report anticipated on PFR and AGC regulation anticipated Fall 2013

Questions?

Debra.Lew@nrel.gov (303) 384-7037

<http://www.nrel.gov/wwwsis>

Erik.Ela@nrel.gov (303) 384-7089

[http://www.nrel.gov/electricity/transmission/
active_power.html](http://www.nrel.gov/electricity/transmission/active_power.html)